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Dear Sir:

Transmitted herewith for filing is the patent application of

Inventor(s): **Henrik K. Nielsen, Lionel Kuhlmann, Mark Nokes**

For: **DETECTION SYSTEM FOR NANOMETER SCALE TOPOGRAPHIC
MEASUREMENTS OF REFLECTIVE SURFACES**

Enclosed are:

- 8 Sheet(s) of drawings (X informal)
- X An assignment of the invention to KLA Tencor Corporation
- An associate power of attorney.
- A verified statement to establish small entity status under 37 CFR 1.9 and 1.27.
- X Declaration and Power of Attorney.
- Certified copy of Patent Application No. filed from which priority is claimed under 35 USC §119.
- IDS enclosed. with references.
- Preliminary Amendment

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ITEM		NO. OF CLAIMS FILED MINUS BASE*		NO. OF CLAIMS OVER BASE	X SM/LG ENTITY FEE	\$ AMOUNT	\$ FEE	
A	TOTAL CLAIMS FEE	60	- 20* =	40	X \$9 or X \$18	\$720		
B	INDEPENDENT CLAIMS FEE**	8	- 3* =	5	X \$39 or X \$78	\$390		
C	SUBTOTAL - ADDITIONAL CLAIMS FEE (ADD FINAL COLUMN IN LINES A + B)						\$1,110	
D	MULTIPLE DEPENDENT CLAIMS FEE				SMALL ENTITY FEE = \$135 LARGE ENTITY FEE = \$270		\$	
E	BASIC FEE*	760.00 OP			SMALL ENTITY FEE = \$380 LARGE ENTITY FEE = \$760		\$760.00	
F	TOTAL FILING FEE (ADD TOTALS FOR LINES C, D, AND E)						\$1,870	
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**LIST INDEPENDENT CLAIMS 1, 18, 24, 32, 37, 48, 52, 59								

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— The issue fee set in 37 CFR 1.18 at or before mailing of the Notice of Allowance, pursuant to 37 CFR 1.311(b).

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Respectfully submitted,


Steven W. Smyrski
Reg. No. 38,312

Date: November 18, 1998

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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In re application of:)
Henrik K. Nielsen, Lionel Kuhlmann,)
Mark Nokes)
Serial No:)
Filed: November 18, 1998)
For: DETECTION SYSTEM FOR)
NANOMETER SCALE TOPOGRAPHIC)
MEASUREMENTS OF REFLECTIVE)
SURFACES)

Art Unit:
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DETECTION SYSTEM FOR NANOMETER SCALE TOPOGRAPHIC
MEASUREMENTS OF REFLECTIVE SURFACES

BY

Henrik K. Nielsen
Lionel Kuhlmann
Mark Nokes

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DETECTION SYSTEM FOR NANOMETER SCALE TOPOGRAPHIC
MEASUREMENTS OF REFLECTIVE SURFACES

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to the art of optical inspection of specimens, such as semiconductor wafers and hard disk surfaces, and more specifically to a system for determining surface topographies in the nanometer range using optical techniques.

Description of the Related Art

Optical inspection techniques for specimens, such as semiconductor wafers, have assessed the relative flatness of specimen surfaces using various techniques. Surface flatness is a critical parameter used to determine the overall quality of a semiconductor wafer, and wafers having large irregular areas or small areas with radical height differences are undesirable.

Current tools available to measure wafer surface flatness include the "Magic Mirror" tool by Hologenix. The "Magic Mirror" operates by directing collimated light toward the wafer surface, wherein the collimated light source is angularly displaced from the wafer surface. The "Magic Mirror" system subsequently receives the reflected light. Light may be scattered toward or away from the detector. The "Magic Mirror" thereupon produces a two dimensional depiction of the surface of the observed semiconductor wafer, with associated light and/or dark areas depending on the type of defect. As can be appreciated, the "Magic Mirror" is a very subjective method of detecting surface contours. With different types of defects producing different optical effects, one cannot say for certain what type or size of defect is responsible for the bright or dark spot or area in the "Magic Mirror" depiction. Hence algorithms cannot

conclusively provide areas of concern or threshold exceedance with reasonable degrees of certainty. The final two dimensional representation obtained from the "Magic Mirror" must be studied by an operator, and results depend on many uncontrollable factors.

An alternate method for measuring surface contours utilizes a profiler, much like a stylus on a record player, which directly contacts the semiconductor wafer surface. Such a system moves the semiconductor wafer and sensor relative to each other causing the sensor to linearly translate across the surface, thereby providing contact between the profiler and the entire surface. Movement of the profiler is recorded, and surface irregularities are detected when the profiler deflects beyond a threshold distance. The problems inherent in a profiler are at least twofold: first, a mechanical profiler contacting the wafer surface may itself produce surface irregularities beyond those present prior to the testing, and second, the time required to make accurate assessments of surface irregularities is extensive. For example, a full map of a single 200 mm wafer using a profiler may take between four and twelve hours.

A system is needed which diminishes the time required to perform surface scanning for contour differences and does not have the drawbacks inherent in previously known systems. In particular, it would be desirable to have a system for determining contours in the nanometer range which would not risk damage to the specimen surface and would be quantitative in nature, thereby allowing for computational determination of surface irregularities using thresholding without ad hoc human review.

It is therefore an object of the current invention to provide a system for determining the contours of the surface of a specimen, such as a semiconductor wafer, in the nanometer

range which can perform surface irregularity determination in less time than systems previously known.

It is a further object of the current invention to provide a system for determining the contours of the surface of the wafer which does not include non-quantitative measurement techniques.

It is a further object of the current invention to provide a system for determining the contours of a wafer surface which does not increase the risk of damaging the wafer surface.

SUMMARY OF THE INVENTION

According to the present invention, there is provided a linear position array detector system which imparts light energy in a substantially normal orientation to a surface of a specimen, such as a semiconductor wafer, receives light energy from the specimen surface and monitors deviation of the retro beam from that expected.

In accordance with the current invention, a laser, such as an argon ion laser, emits a beam toward an optical isolator, which prevents the retro-beam from entering back into the laser, thereby causing laser instability. The beam is thereupon directed through a series of focusing optics and mirrors onto the surface of the specimen. Optionally, the beam may be caused to pass through polarization optics and a birefringent prism, which produces two beams of orthogonal polarization that diverge from each other by a small angle. This angular divergence results in a physical separation of the two beams at the focus of the optical system on the specimen surface, in the same manner as that used in Nomarski differential interference contrast (DIC) microscopy. DIC microscopy is illustrated in U.S. Patent 5,798,829 to Mehdi Vaez-Iravani, entitled "Single Laser Bright Field and Dark

Field System for Detecting Anomalies of a Sample", issued August 25, 1998 and assigned to KLA-Tencor Corporation.

After the split beam contacts the specimen surface, the light scattered at a narrow angle to the incident beam from surface defects is collected in the Dark Field Narrow (DFN) channel, while most of the light scattered at larger angles by the surface defects is collected in the Dark Field Wide (DFW) channel. The remainder of the beam is specularly reflected back through the components outlined above. As two beams illuminate the wafer surface, two beams are returned through the elements up to the birefringent prism, which combines the two retro beams into a single beam. The single beam is returned through the remaining elements.

The retro beam will, with ideal optical alignment, return along the same path as the incident beam if and only if the surface is normal to the beam. The current invention provides a measurement device or sensor within the path of the retro beam to measure deviation of the retro beam from expected. The system uses a diode/detector array, which is preferably a multiple element array of detector-diodes aligned in a linear fashion. The system could be implemented using a CCD sensor or other sensor, but these devices have certain drawbacks. The diode/detector array can be positioned proximate the optical isolator to receive the retro beam, or alternately a polarizing or non-polarizing beamsplitter may be employed in the retro path to divert the retro beam. The beam wander results in the retro beam illuminating different diodes in the array. Weighting the signal from each detector with a weight proportional to the relative position of the beam and adding signals from all detectors in conjunction with a signal normalization using the total detected light power provides a linear voltage proportional to the beam position independent of the absolute light power level.

5 The preferred diode/detector array is made up of 76
adjacent detector elements each having the ability to have
electrical connections at exposed ends of the element. Each
diode has a 280 micrometer length with 30 micrometers between
10 elements. The entire mechanical dynamic range of the array in
this longest direction is 23.56 millimeters. The width of
these elements is 6.35 millimeters, and thus mechanical
alignment is non-critical for a one millimeter diameter beam.
The beam in the present arrangement, as described in more
15 detail below, is 22 micrometers by 50 or 340 micrometers at
the focal point on the specimen, but 1 mm in diameter at the
detector. It may be appreciated by those of ordinary skill in
the art that diode arrays having different sizing or
composition of elements may be employed while still within the
scope of the current invention.

20 The system measures output from each of the 76 elements
in the array and calculates the center of mass for the entire
arrangement. The relative power of the beam being Gaussian
dictates that the arrays be sized such that the expected
beamwidth spans several array elements. The system operates
by scanning the wafer and monitoring movement of the retro
beam from expected.

25 Each diode detector in the 76 element diode/detector
array uses a pre-amplifier. To preserve sensitivity, the pre-
amplifier gain must be relatively high, which is undesirable.
Thus the invention further includes a scheme to increase the
mechanical dynamic range while preserving sensitivity.

30 The signals from each individual diode are summed using a
conventional inverting sum amplifier. Weighting resistors 1
through n provide resistances R , $3 \cdot R$, through $[(2 \cdot n) - 1] \cdot R$,
thereby providing weighting of the signals received from the
sensor array. One summing amplifier is used for each group of
amplifiers, wherein each group has 5 amplifiers and
accordingly 5 array elements. The optimal number of diodes to

be grouped together depends on the laser beam width, diode size, and the gap between the diodes. The system determines the position signal by subtracting the values from two neighbor groups of diodes from one another. A unique stair-stepping arrangement of weightings is employed in the current invention to provide linear response, preserve the dynamic range over the expected path of the retro beam, and prevent saturation of the signal.

Data are selectively passed from the signal groups 1 through n using a multiplexer which receives a digital signal from programmable array logic based on a thresholding arrangement.

This detector as described senses deviations of the specimen surface orientation from normal to the beam along one axis; deviations along the orthogonal axis may be sensed using the optional Nomarski DIC channel by appropriate orientation of the birefringent prism and polarizing optics. Other objects, features, and advantages of the present invention will become more apparent from a consideration of the following detailed description and from the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates the preferred embodiment of the inventive linear position array detector system having a sensor receiving a signal diverted from the input polarizer of the optical isolator;

FIG. 2 is an alternate embodiment of the invention having a sensor receiving a signal diverted from a point within the optical elements using a polarizing or non-polarizing beamsplitter;

FIG. 3 presents a detector array in accordance with the teachings of the present invention having a beam imparted thereon;

FIG. 4 illustrates the relative power of a signal imparted on the diode/detector array of FIG. 3;

FIG. 5 is the diode/pre-amplifier circuit used with each element of the diode/detector array;

FIG. 6 presents the unique weighting/summing scheme and associated amplifier arrangement employed in accordance with the teachings of the current invention;

FIG. 7 shows the weighted summing amplifier, preamplifiers, and diode/detectors used in summing the weighted signals from the 10 centermost diodes in the diode/detector array;

FIG. 8 illustrates the signal from the center group of diodes using the unique weighting scheme of the current invention;

FIG. 9 is a diagram of the stair-stepping dual-weighting arrangement of the current invention, including three summing elements and a position signal selector; and

FIG. 10 presents the programmable logic array and multiplexer arrangement used to determine the output signal of the system.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 illustrates the inventive linear position array detector system. The system may be modified from existing technology, such as the existing SP1 system manufactured by KLA-Tencor Corporation of San Jose, California. The SP1 system may include Stationary Beam Illumination technology and an optional Bright Field scanning Nomarski Differential Interference Contrast sensor.

From FIG. 1, a laser 101, such as an argon ion laser operating at a wavelength of 488 nm, emits a laser beam toward an optical isolator 102. The optical isolator comprises an input polarizer 118, a Faraday effect polarization rotator 119, and an output polarizer 120, and operates to rotate the

polarization of any beam passing through it by 45 degrees from its incident polarization. The polarizers are oriented to pass the outgoing linearly polarized beam from the laser. The retro beam's polarization will be normal to the pass direction of input polarizer 118 after passing through the Faraday cell 119, however, and will thereby be attenuated before it enters the laser cavity and causes instability. The beam is thereupon directed toward a mirror 103 and down through a half wave plate 104. The beam may optionally be directed through a polarizing beamsplitter 105, discussed below, and toward a birefringent, or DIC (differential interference contrast), prism 106. The DIC prism 106 operates to split the incoming linearly polarized beam into two separate beams of orthogonal linear polarization that diverge from each other by a small angle. These two beams then pass through an optics arrangement 107, which comprises a series of lenses used to focus the beams toward the wafer surface. The focused beams are directed to second mirror element 108, which directs the beam toward third mirror element 109 and onto the surface of the wafer 110. As shown herein, the beam is stationary as opposed to scanning beams used in other known optical inspection devices.

The optics arrangement 107 includes first lens 111, mask 112, second lens 113, third lens 116, and fourth and fifth lens combination 115, comprising fourth lens 115a and fifth lens 115b. These lenses in the optics arrangement 107 shape and focus the light beams to fix at a desired spot size on the surface of the wafer 110.

As illustrated in FIG. 1, the stationary laser beam intercepts the wafer surface at normal incidence. After the split beam contacts the wafer surface it is reflected back through the components shown, particularly onto third mirror element 109, second mirror element 108, optics arrangement 107, DIC prism 106, polarizing beamsplitter 105, half wave

plate 104, first mirror element 103, and optical isolator 102. Again, two beams illuminate the wafer surface, and two beams are thus returned to third mirror element 109, second mirror element 108, optics arrangement 107, and to DIC prism 106.

5 DIC prism 106 combines the two retro beams into a single beam, which is returned through the remaining elements illustrated and toward laser 101. The optical isolator 102 attenuates the beam significantly by orthogonal polarization rejection at polarizers 120 and 118, respectively.

10 While the system disclosed herein illustrates a normal application of a beam to the specimen 110, it is to be understood that the teachings of the current invention contemplate application of a beam to a specimen in non-normal or oblique angles. As used herein, the term "retro" or "retro beam" is intended to cover both normal and non-normal reflection of the beam from the specimen.

15 Portions of the current system resemble the system disclosed in pending U.S. Patent Application 08/933,771 to Mehdi Vaez-Iravani et al., filed September 19, 1997 and assigned to KLA-Tencor Corporation, the entirety of which is incorporated herein by reference.

20 In the configuration illustrated for the invention disclosed herein, two spot sizes have been successfully employed to perform the tasks described herein. One spot size is a 22 micron by 50 micron spot, while the other is a 22 micron by 340 micron spot. The spot size used is selected by using either lens 113 or lens 114. As may be appreciated by those of skill in the art, the larger spot size provides a higher throughput but has a tendency to produce lower quality scans, as lower power applied to the surface of the wafer yields less sensitivity. As disclosed herein, various spot sizes may be employed successfully with this invention, including the two disclosed herein, while still within the scope of the invention. Generally speaking, a larger spot

size will yield less sensitivity and greater throughput while a smaller spot size will produce greater sensitivity but take longer to complete a scan.

5 The retro beam will, with ideal optical alignment, return along the same path as the incident beam if and only if the surface is normal to the beam. With this knowledge, a measurement device or sensor can be located within the path illustrated in FIG. 1 to measure deviation of the retro beam from the transmitted beam.

10 The current system provides the ability to perform a deviation measurement using the bright field scanning Nomarski Differential Interference Contrast sensor 106. The bright field scanning Nomarski Differential Interference Contrast sensor 106 splits the beam into two separate beams which are applied to the surface of the specimen 110 as shown in FIGs. 1 and 2 and outlined above. The specimen 110 is rotated about a vertical axis and concurrently translated horizontally during a typical scan while the beam remains stationary. As a result of the scanning process, the Nomarski DIC sensor 106 senses occurrences in a predetermined direction, such as in a tangential direction from the center of the specimen, while the optical lever created by the optics senses occurrences in an orthogonal direction to that of the Nomarski DIC sensor 106. While the system may use the Nomarski DIC sensor 106 to measure in the tangential direction and the optical lever to measure in the radial direction, it is to be understood that other orientations are possible but it is preferred that the Nomarski DIC sensor and optical lever are always orthogonal to one another.

30 FIG. 1 illustrates one embodiment of the system with a diode/detector array 117 receiving the retro beam from the isolator's input polarizer 118. While the diode/detector array, as will be described below, is preferably a multiple element array of detector-diodes, the system could be

implemented alternately using a CCD sensor, which has certain drawbacks. The system illustrated in FIG. 2 presents an alternate positioning of the diode/detector array 117. The diode/detector array 117 in FIG. 1 is positioned proximate the optical isolator 102 to divert the retro beam using input polarizer 118. Alternately, the diode detector/array 117 may be positioned just before the DIC prism in the incident path such that the polarizing beamsplitter 105 diverts the retro beam toward the detector array, as illustrated in FIG. 2. In either condition, the retro beam is deflected from the path toward the diode/detector array, and any deviation from normal constitutes a local wafer surface irregularity. The beam wander results in the retro beam illuminating different diodes in the array, discussed below. Weighting the signal from each detector with a weight proportional to the relative position of the beam and adding signals from all detectors in conjunction with a signal normalization using the total detected light power provides a linear voltage proportional to the beam position independent of the absolute light power level. The system measures the summed diode signal and at the same time records the (x,y) or (r, θ) position on the wafer and generates a map of relative surface slopes. The integrated signal of the slope map produces a surface topography or surface height map.

A sample detector array having a beam imparted thereon is illustrated in FIG. 3. The diode/detector array 117 is made up of 76 adjacent detector elements each having the ability to have electrical connections at exposed ends of the element. Different sized arrays may be employed while still within the scope of the current invention; however, as discussed below, large two-dimensional blocks of detectors have speed and size/sensitivity concerns which are undesirable. The overall diode/detector array 117 includes 76 diodes, each diode having a 280 micrometer length with 30 micrometers between elements.

The entire mechanical dynamic range of the array in this longest direction is 23.56 millimeters. The width of these elements is 6.35 millimeters, and thus mechanical alignment is non-critical for a one millimeter diameter beam.

5 According to the arrangement presented in FIGs. 1 and 2 in conjunction with the diode/detector array 117 illustrated, the system measures output from each of the 76 elements in the array and calculates the center of mass for the entire arrangement, normalized with the total detected light power.

10 From FIG. 3, the beam is nominally positioned at a predetermined location in the retro beam path when the system according to FIGs. 1 or 2 is operating. The relative power of the beam is Gaussian, as shown in FIG. 4. The arrays are preferably sized such that the expected beamwidth spans
15 several array elements, and as shown in FIG. 3, the beam spans six elements of the array. The arrangement shown preserves the sensitivity of the system over a larger mechanical dynamic range than, for example, a bi-cell wherein the beam strikes two cells in the two cell array. The system operates by
20 scanning the wafer and monitoring the movement of the retro beam from the nominal value in the sensor array arrangement shown in FIG. 3. Typical beam deflection in the FIG. 3 arrangement is right to left, meaning that the beam will typically travel right or left in the presence of anomalies on
25 the wafer surface.

Each diode detector in the 76 element diode/detector array 117 operates with a pre-amplifier as shown in FIG. 5. The pre-amplifier is configured as a conventional trans-conductance amplifier having low pass filtering. Amplifier
30 501 has resistor 502 and capacitor 503 connected in parallel therewith in a feedback orientation. Diode 504 represents one of the 76 diodes in the array. Each diode, such as diode 504 of FIG. 5, operates in a photo-conductive mode, or in other words operates with a bias voltage. The feedback resistor 502

determines the gain of the amplifier, while the resistor and the capacitor act as a single pole low pass filter having a time constant equal to RC . This provides a -3 dB cutoff frequency.

5 In order to preserve sensitivity for the arrangement shown, the pre-amplifier gain must be relatively high. High preamplifier gain results in an increased position signal which can be too large for an analog to digital converter. Thus the configuration shown requires a scheme to increase the
10 mechanical dynamic range while preserving sensitivity, which can be on the order of less than .000001 rad for the system illustrated.

15 The signals from each individual diode are summed as shown in FIG. 6 using a conventional inverting sum amplifier. From FIG. 6, the weighted summing amplifier includes amplifier 601, parallel feedback resistor 602, and parallel capacitor 603. Weighting resistors 611, individually denoted 1 through
20 n , are of resistances R , $3R$, through $[(2n)-1] * R$, thereby providing weighting of the signals received from the sensor array. Weighting provides a skewing of information based on the position of the beam; for a beam which is further away than expected, the signal returned from the arrangement of
25 FIG. 6 and subsequent drawings is larger than that of a beam which is only slightly off center. One summing amplifier is used for each group of amplifiers as shown in FIG. 7, wherein each group has five amplifiers and accordingly five array elements. The optimal number of diodes to be grouped together depends on the laser beam width, diode size, and the gap between the diodes. The system determines the position signal
30 by subtracting the values from two neighbor groups of diodes from one another; for example, from FIG. 7, each element in the array has a diode associated therewith along with a preamplifier in accordance with FIG. 5. Each preamplifier has a weight associated therewith, and as shown in FIG. 7, the

center elements are numbered 1 and 2, are each attached to preamplifiers, and are weighted with a value of 1. The outermost elements are numbered 9 and 10 and have diodes associated therewith, as well as preamplifiers as in FIG. 5. The outermost elements have weights of 9 associated therewith. Thus the summing amplifiers 701 and 702 receive the weighted signals and compare them in summation element 703. The result of this comparison is the position signal for this diode group of 10 diodes, which is then compared with position signals from other groups of 10 diodes.

The center group illustrated in FIG. 7 outputs a signal relative to the beam offset as shown in FIG. 8. Nominal beam offset provides a minimal return, out to an approximately 1200 micrometer offset which produces a relative return of ± 1.0 .

FIG. 9 illustrates the stair-stepping arrangement of weightings used in accordance with the current invention for the 76 diode/array element arrangement of FIG. 3. As shown herein, 20 of the 76 diodes or array elements of the diode/detector array 117 each are connected to resistors, or weighting elements, which provide weighting according to relative position. For example, diode/array element 1 is multiplied by 9 in weighting resistor group 901 and also by 1 in weighting resistor group 904. Diode/array element 2 is multiplied by 9 in weighting resistor group 902 as well as by 1 in weighting resistor group 904. This stair-stepping dual-weighting arrangement permits a relatively linear response across the diode/detector array 117 by essentially mixing weights of adjacent resistors and not overweighting or underweighting areas of the diode/detector array 117, while concurrently providing significant signal deviation upon slight beam movement. The arrangement shown prevents saturation of the signal and preserves the dynamic range over the expected path of the retro beam. From FIG. 9, elements 1, 3, 5, 7, . . . 19 are weighted in weighting resistor group

901, with elements 9 and 11 each receiving weight 1 and elements 1 and 19 receiving weight 9. These elements are summed in position signal group 3 summing element 906. Simultaneously, elements 1, 3, 5, 7, and 9 are weighted with elements 2, 4, 6, 8, and 10 in weighting resistor group 904, thereby avoiding overweighting of element 1 or underweighting of element 9. The ten elements 1 through 10 are summed in position signal group 1 summing element 907. All position signal groups provide information to position signal selector 1001, which converts the information into a position signal.

As may be appreciated from a review of the stair-stepping arrangement of FIG. 9, the ends of the 76 element array will each have a lone grouping of 5 elements and 5 weights which will normally not be summed with other elements. Various options are available in this edge condition. First, the second set of weighting elements may be omitted and the signal from the pertinent five elements only summed with one position signal group rather than the two used for all other diode/detector elements. Alternately, the two groups of five leftover elements may be compared to one another, but this is less desirable. It is recommended that the edge elements simply be weighted and summed using only a single weighting element, rather than the two weighting elements used by the non-edge groups of diode/detector elements.

FIG. 10 illustrates passing of data from the various signal groups 1 through n to a multiplexer 1003, which receives a digital signal from programmable array logic (PAL) 1002. From FIG. 10, the system generates a group total detector power for each group in addition to the signal. The power of each group is compared to a given power threshold, and based on the output of these comparisons, the system uses the PAL 1002 to decide which group should be made active. In other words, the PAL determines which group has exceeded the required threshold, passes that group number to the

5 multiplexer 1003, and the multiplexer 1003 only passes the
desired group as output. At any given moment, only the group
of detectors containing the most power are passed to the
system and are used to determine position. The arrangement
shown eliminates the electronic and detector noise associated
with detectors not containing any signal.

10 The resultant system provides resolution for various
types of anomalies on the wafer surface. Whereas conventional
flatness tools had the ability to address problems with
bowing/warping, site flatness or thickness variations, and
polishing dimples by evaluating relatively large height errors
coupled with relatively large lateral dimensions, such tools
did not have the ability to detect small height differences
and small diameter defects, which required a conventional
defect tool. The conventional defect tool could detect
15 particles, scratches, haze, microroughness, and other
miscellaneous small extent defects. Certain undesirable
surface features had been undetectable using either
conventional flatness tools or defect tools, particularly in
situations involving device geometries for which relative
20 surface height variations of 100 nanometers or less are
significant. The current system provides the ability to
address these mid-range concerns, and scanning using the
current system takes on the order of minutes rather than
several hours to complete.

25 While the invention has been described in connection with
specific embodiments thereof, it will be understood that the
invention is capable of further modifications. This
application is intended to cover any variations, uses or
adaptations of the invention following, in general, the
30 principles of the invention, and including such departures
from the present disclosure as come within known and customary
practice within the art to which the invention pertains.

WE CLAIM:

1. A system for inspecting a specimen, comprising:
a light generating device;
an optical element arrangement for receiving light from
said light generating device and imparting light toward said
specimen and receiving a retro beam from said specimen;
a retro beam diversion element for diverting the retro
beam from said optical element arrangement; and
a sensing device for receiving and sensing retro beam
position upon diversion from said optical element arrangement,
said sensing device having dimensions and an orientation to
favorably receive said retro beam based on a predetermined
expected diversion thereof.

2. The system of claim 1, wherein said optical element
arrangement comprises an optical isolator.

3. The system of claim 2, wherein said system further
comprises:
a birefringent prism;
a lensing arrangement for receiving light energy from
said birefringent prism;
at least one mirror, wherein one mirror receives light
energy from said optical isolator; and
a half wave plate for receiving light energy from said
one mirror and transmitting light energy to said birefringent
prism.

4. The system of claim 2, wherein said optical element
arrangement further comprises a dark field collection
arrangement.

5. The system of claim 1, wherein said optical element
arrangement comprises an optical isolator, and said retro beam

diversion element diverts light energy received from said optical isolator.

6. The system of claim 1, wherein said retro beam diversion element comprises a beamsplitter.

5 7. The system of claim 1, wherein said specimen comprises a surface, and wherein said sensing device senses diversion of said retro beam from an expected value and said system further comprises means for mapping a two dimensional x-y representation of the specimen surface based on signals
10 received from said sensing device.

8. The system of claim 1, wherein said optical element arrangement comprises a Nomarski Differential Interference Contrast sensor.

9. The system of claim 8, wherein said Nomarski
15 Differential Interference Contrast sensor divides light received in a single beam into a plurality of beams; and wherein said optical element arrangement imparts a plurality of beams onto said specimen.

20 10. The system of claim 9, wherein the plurality of beams comprises two beams and wherein the system scans the specimen in a direction substantially parallel to a line joining said two beams.

11. The system of claim 1, wherein said sensing device comprises a one dimensional detector array.

25 12. The system of claim 11, wherein said one dimensional detector array comprises one from the group including a CCD, a position sensitive detector, and a linear diode array.

13. The system of claim 1, wherein said sensing device comprises:

a plurality of detector elements having exposed ends and predetermined spacing between said detector elements;

5 a plurality of electrical connections affixed to said exposed ends of said detector elements; and

a plurality of preamplifiers, wherein each detector element has a preamplifier associated therewith.

14. The system of claim 13, further comprising:

10 a first plurality of weighting elements, each weighting element having a first predetermined weight associated therewith and electrically connected to a preamplifier;

15 a second plurality of weighting elements, said second plurality of weighting elements having a second predetermined weight associated therewith and electrically connected to a preamplifier wherein said first predetermined weight differs from said second predetermined weight; and

20 a plurality of summing amplifiers for receiving and combining weighted signals from predetermined weighting elements;

whereby each preamplifier is electrically connected to two weighting elements.

15. The system of claim 14, further comprising:

25 programmable array logic for receiving signals from said summing amplifiers and predetermined power thresholds and selecting signals to be transmitted based on said predetermined power thresholds; and

30 a multiplexer for receiving output selection signals from said programmable array logic and transmitting appropriate signals from said summing amplifiers.

16. The system of claim 1, wherein said light generating device comprises a laser.

17. The system of claim 1, wherein light is imparted toward said specimen and said retro beam is received in a substantially normal orientation with respect to said specimen.

18. A detector array for detecting light energy, said light energy forming a beam having a predetermined diameter, comprising:

a plurality of elements having exposed ends and predetermined spacing between said elements;

a plurality of electrical connections affixed to said exposed ends of said elements; and

wherein said elements have width less than one third the beam diameter.

19. The detector array of claim 18, further comprising:

a first plurality of weighting elements, each weighting element having a first predetermined weight associated therewith and electrically connected to said preamplifier;

a second plurality of weighting elements, said second plurality of weighting elements having a second predetermined weight associated therewith and is electrically connected to said preamplifier, wherein said first predetermined weight differs from said second predetermined weight; and

a summing amplifier for receiving signals from selected ones of said first plurality of elements and said second plurality of elements.

20. The detector array of claim 19, wherein each preamplifier is electrically connected to two weighting elements.

21. The detector array of claim 18, wherein movement of said beam is sensed by said detector array, and said movement alters electrical signals transmitted from selected elements of said detector array.

5 22. The detector array of claim 21, wherein movement of said beam causes altered transmission of signals to a weighting and summing arrangement.

23. The method of claim 18, further comprising:
a plurality of preamplifiers, wherein each linear diode
10 element has a preamplifier associated therewith.

24. A system for detecting contours on a specimen surface, comprising:
means for applying light energy to said specimen surface;
and
15 means for detecting surface variations having relative surface height variations of less than approximately 1000 nanometers and surface contours over areas larger than particles and scratches.

25. The system of claim 24, wherein said detecting means
20 comprise optical relaying means for transmitting light energy received from said light energy applying means to said specimen surface and receiving a retro beam deflected therefrom.

26. The system of claim 24, further comprising:
25 an optical diversion element; and
sensing means for detecting movement of said retro beam;
wherein said sensing means receive the retro beam
diverted by said optical diversion element.

27. The system of claim 26, wherein said sensing means comprise a linear array of sensors.

28. The system of claim 25, further comprising:
sensing means; and

weighting and summing means for weighting and summing information received from said sensing means.

29. The system of claim 28, further comprising programmable array logic and a multiplexer, wherein said programmable array logic determines signals based on predetermined threshold exceedance and initiates any determined signal via said multiplexer.

30. The system of claim 24, wherein said detecting means have the ability to detect surface variations having relative surface height variations of less than approximately 1000 nanometers and greater than approximately 1.0 nanometer.

31. The system of claim 30, wherein said detecting means have the ability to detect surface variations having relative surface height variations of less than approximately 1000 nanometers and greater than approximately 0.1 nanometer.

32. A system for weighting data received from an electrical sensing array, said electrical sensing array including a plurality of elements, comprising:

a plurality of preamplifiers each electrically connected to one of said plurality of elements;

a first plurality of weighting elements, each weighting element having a first predetermined weight associated therewith and electrically connected to said preamplifier;

a second plurality of weighting elements, said second plurality of weighting elements having a second predetermined

weight associated therewith and is electrically connected to said preamplifier, wherein said first predetermined weight differs from said second predetermined weight; and

at least one summing amplifier;

whereby each preamplifier is electrically connected to two weighting elements.

33. The system of claim 32, wherein each summing amplifier receives and combines weighted signals from predetermined weighting elements.

34. The system of claim 32, wherein:
said first plurality of weighting elements is associated into at least one group;
said second plurality of weighting elements is associated into at least one group; and
each summing amplifier receives information from a group.

35. The system of claim 32, further comprising:
programmable array logic for receiving signals from said summing amplifiers and predetermined power thresholds and determining those signals to transmit based thereon.

36. The system of claim 35, further comprising:
a multiplexer for receiving output selection signals from said programmable array logic and transmitting appropriate signals from said summing amplifiers.

37. A method for inspecting a specimen, comprising the steps of:

imparting light energy toward an arrangement of optical elements;

providing light energy to said specimen via an arrangement of optical elements, thereby creating a retro beam reflected from said specimen;

5 passing said retro beam back through said arrangement of optical elements; and

providing said retro beam to a sensing device, said retro beam having an expected diversion in a substantially predetermined direction and said sensing device being substantially linearly dimensioned and oriented to receive diversions of said retro beam in said substantially predetermined direction;

10 wherein said sensing device senses movement of the retro beam corresponding to anomalies on said specimen.

38. The method of claim 37, wherein said optical element arrangement comprises:

a birefringent prism; and

a lensing arrangement, said lensing arrangement comprising a plurality of optical lenses.

39. The method of claim 38, wherein said optical arrangement further comprises:

an optical isolator;

a half wave plate; and

at least one mirror.

40. The method of claim 37, wherein said optical element arrangement comprises an optical isolator, and said retro beam providing step diverts light energy received from said optical isolator.

41. The method of claim 37, wherein said retro beam providing step comprises diverting the retro beam via a beamsplitter.

42. The method of claim 37, wherein said optical element arrangement comprises a bright field scanning Nomarski Differential Interference Contrast sensor.

5 43. The method of claim 42, wherein said bright field scanning Nomarski Differential Interference Contrast sensor measures deviation along a direction substantially perpendicular to an optical lever.

44. The method of claim 37, wherein said sensing device comprises:

10 a plurality of detector elements having exposed ends and predetermined spacing between said elements;

a plurality of electrical connections affixed to said exposed ends of said detector elements; and

15 a plurality of preamplifiers, wherein each element has a preamplifier associated therewith.

45. The method of claim 37, wherein said optical element arrangement comprises a bright field scanning Nomarski Differential Interference Contrast sensor.

20 46. The method of claim 45, wherein bright field scanning Nomarski Differential Interference Contrast sensor measures deviation along a direction substantially perpendicular to the orientation of beams created thereby.

25 47. The method of claim 37, wherein said light energy is provided to said specimen in a substantially normal orientation.

48. A method for detecting contours on a specimen surface, comprising:

applying light energy to said specimen surface; and

detecting surface variations having relative surface height variations of less than approximately 1000 nanometers and surface contours over areas larger than particles and scratches.

5 49. The method of claim 48, wherein said detecting step comprises transmitting light energy received from said light energy applying step to said specimen surface and receiving a retro beam deflected therefrom.

10 49. The method of claim 48, further comprising the steps of:

 optically diverting light energy after said applying step; and

 detecting movement of said retro beam by receiving the retro beam diverted by said optical diversion step.

15 51. The method of claim 48, further comprising the steps of weighting and summing information received from said detecting step.

 52. A method for inspecting the surface of a specimen, comprising the steps of:

20 (a) providing at least three linearly arranged elements having exposed ends and predetermined spacing therebetween; and

 (b) imparting a substantially Gaussian light beam onto said plurality of linearly arranged elements, wherein said beam has the expected ability to move in a predetermined direction substantially collinear with said plurality of linearly arranged elements;

25 wherein said beam spans at least three of said linearly arranged elements.

53. The method of claim 52, further comprising the steps of:

(c) imparting light energy toward an arrangement of optical elements;

(d) providing light energy to a specimen via an optical element arrangement, thereby creating a retro beam reflected from said specimen;

(e) passing said retro beam back through said arrangement of optical elements, thereby creating said substantially gaussian light beam;

wherein steps (c), (d), and (e) occur prior to step (b).

54. The method of claim 53, wherein said optical element arrangement comprises:

a birefringent prism; and

a lensing arrangement, said lensing arrangement comprising a plurality of optical lenses.

55. The method of claim 54, wherein said optical element arrangement further comprises:

an optical isolator;

a half wave plate; and

at least one mirror.

56. The method of claim 53, wherein said optical element arrangement comprises a bright field scanning Nomarski Differential Interference Contrast sensor.

57. The method of claim 56, wherein said bright field scanning Nomarski Differential Interference Contrast sensor splits said beam into two beams, and wherein said providing step comprises scanning said two beams of light over said specimen at a substantially orthogonal angle to an optical lever.

58. The method of claim 52, wherein said linearly arranged elements further comprise:

a plurality of electrical connections affixed to said exposed ends of said elements; and

5 a plurality of preamplifiers, wherein each linear diode element has a preamplifier associated therewith.

59. A method of measuring surface topography of an object, comprising the steps of:

10 measuring said surface topography along a first axis using a first optical technique; and

15 simultaneously measuring said surface topography along a second axis at an angle offset from said first axis using a second optical technique different from said first technique while maintaining relative motion between said object and a system for performing said first and second measurements.

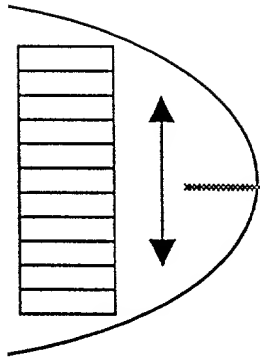
60. The method of claim 59, wherein said first axis is orthogonal from said second axis.

ABSTRACT OF THE DISCLOSURE

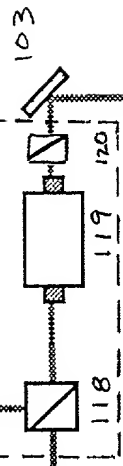
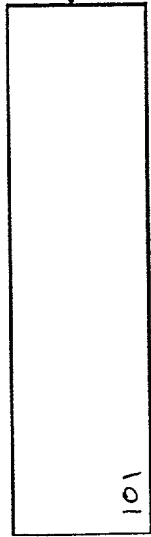
5 A linear position array detector system is provided which imparts light energy to a surface of a specimen, such as a semiconductor wafer, receives light energy from the specimen surface and monitors deviation of the retro or reflected beam from that expected to map the contours on the specimen surface. The retro beam will, with ideal optical alignment, return along the same path as the incident beam if and only if the surface is normal to the beam. The system has a measurement device or sensor within the path of the retro or reflected beam to measure deviation of the retro beam from expected. The sensor is preferably a multiple element array of detector-diodes aligned in a linear fashion. A unique weighting and summing scheme is provided which increases the mechanical dynamic range while preserving sensitivity. The system further includes a bright field Nomarski Differential Interference Contrast sensor used to split the beam into two beams and for scanning in an orientation orthogonal to the orientation of the optical lever created by the system.

Patented Dec 15, 1998

117



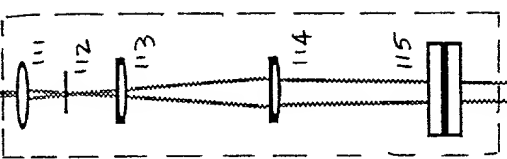
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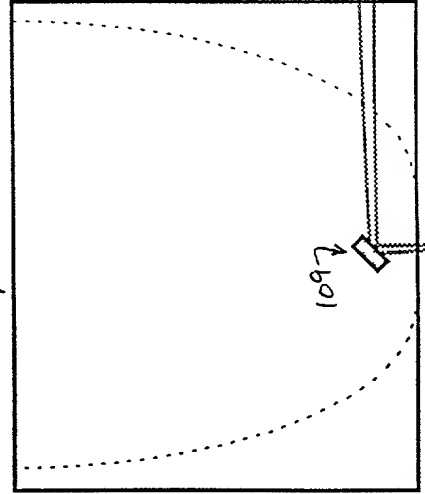
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Fig. 1

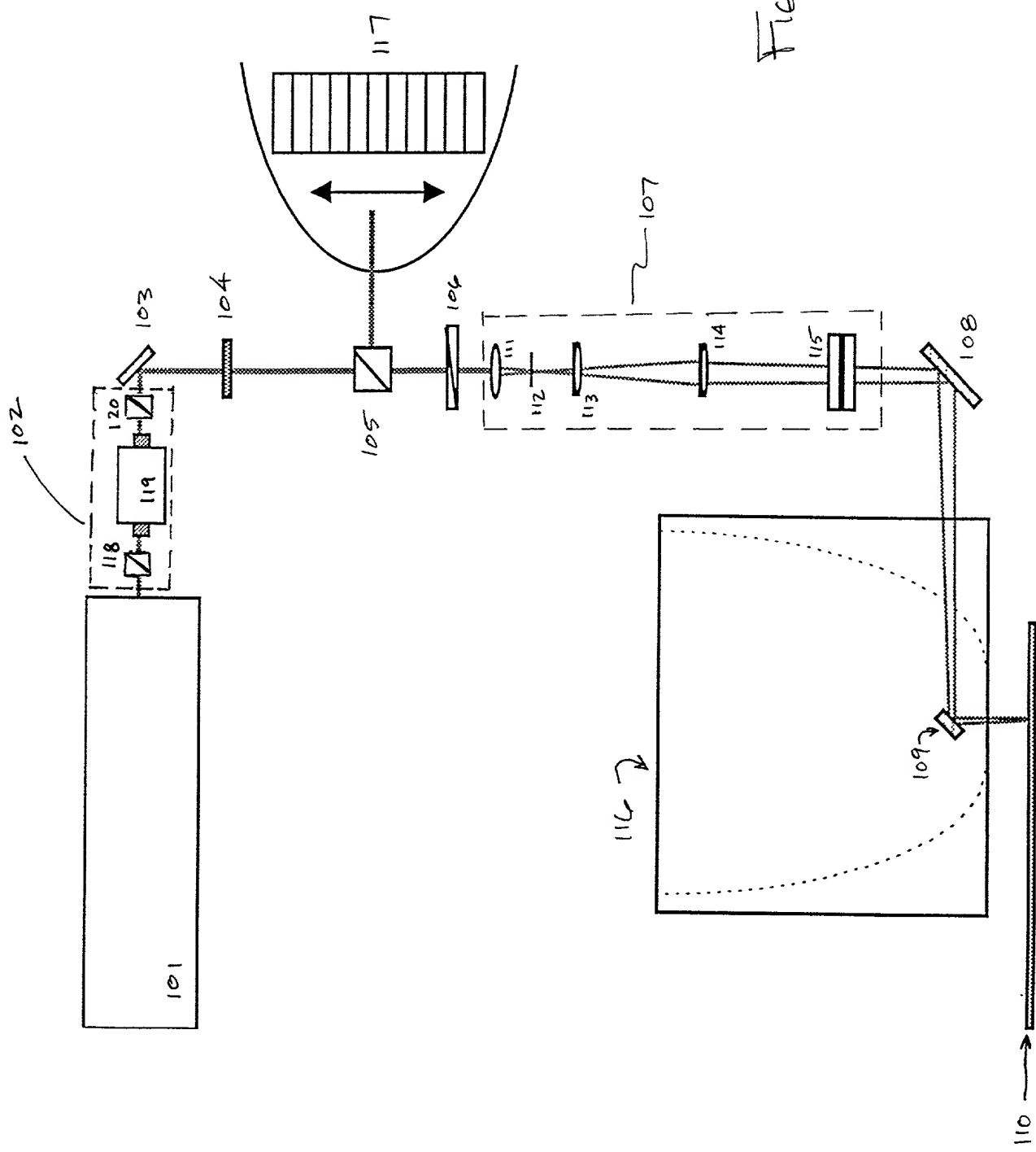
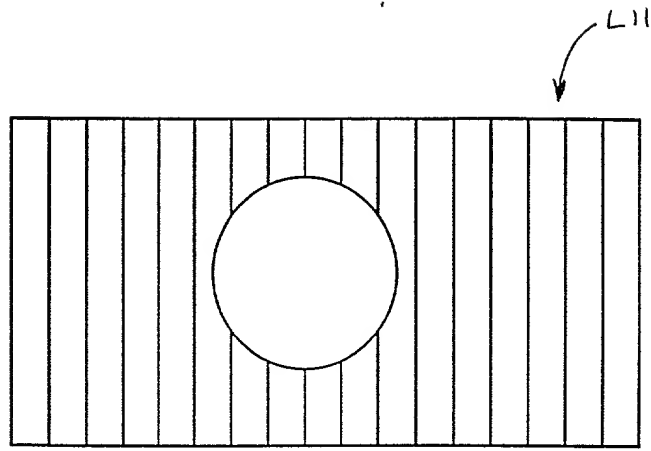
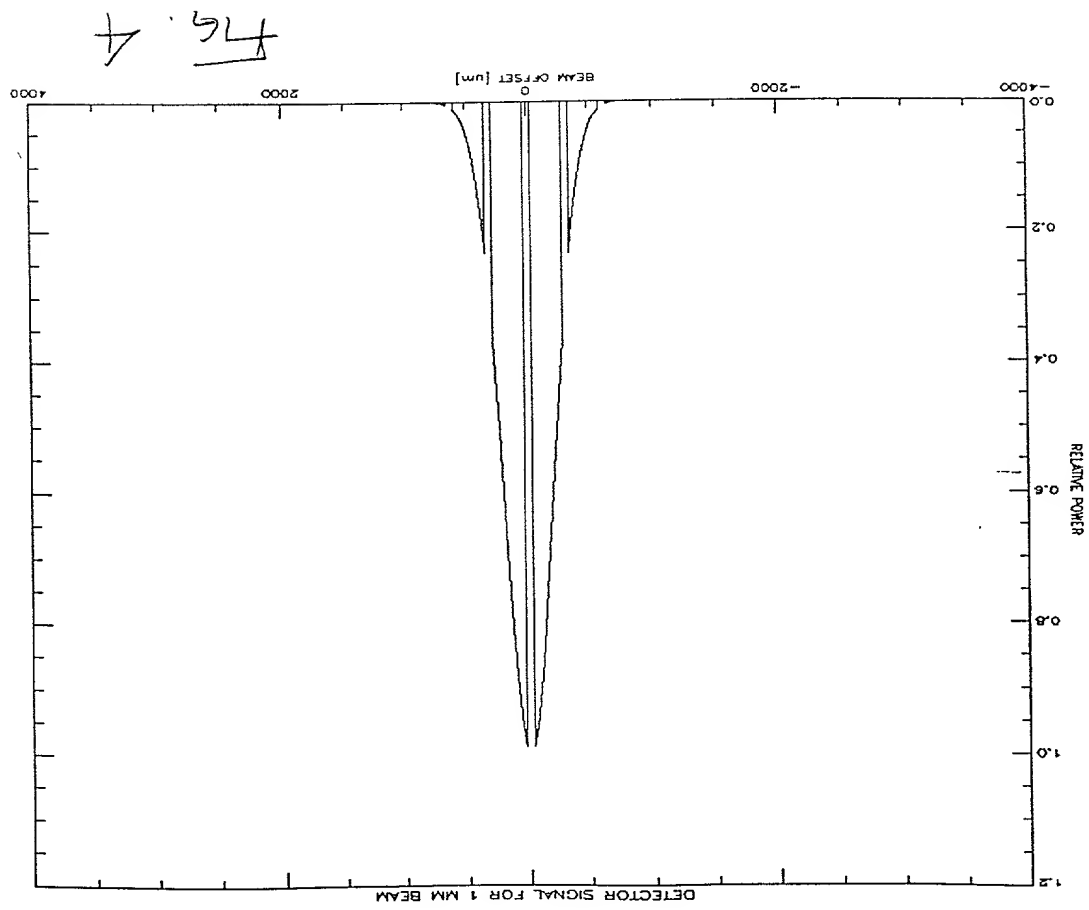


Fig. 2

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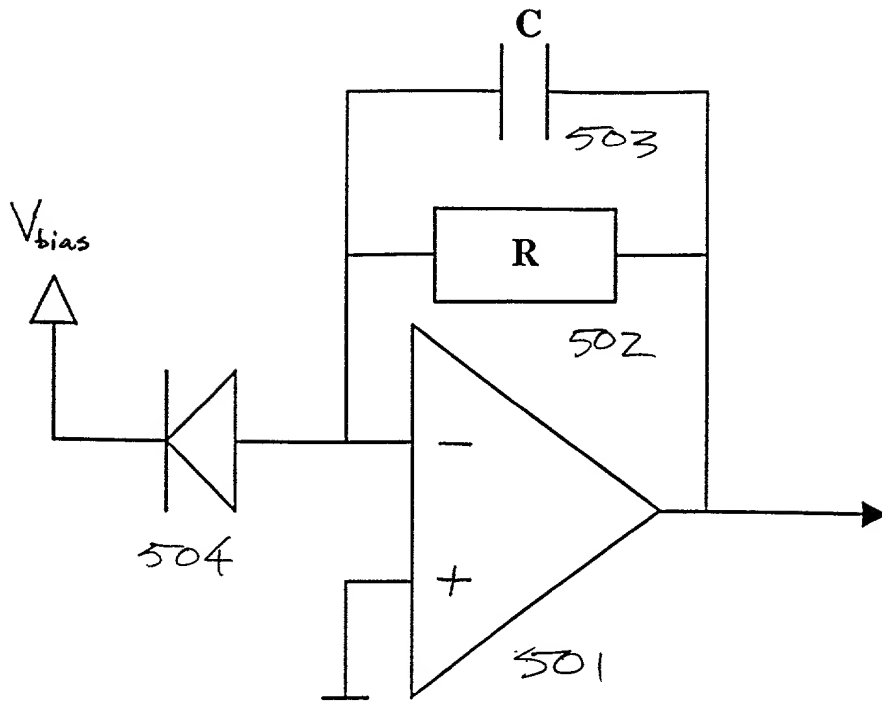


Fig. 5

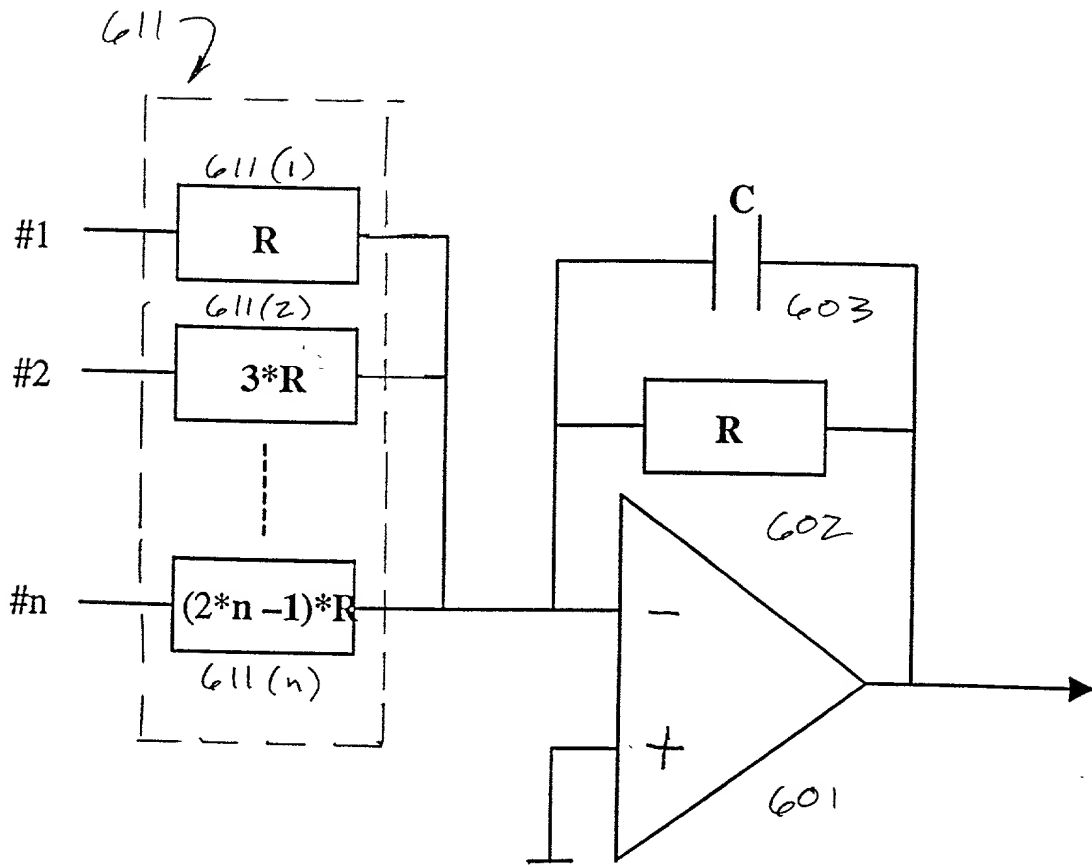


Fig. 6

SECRET

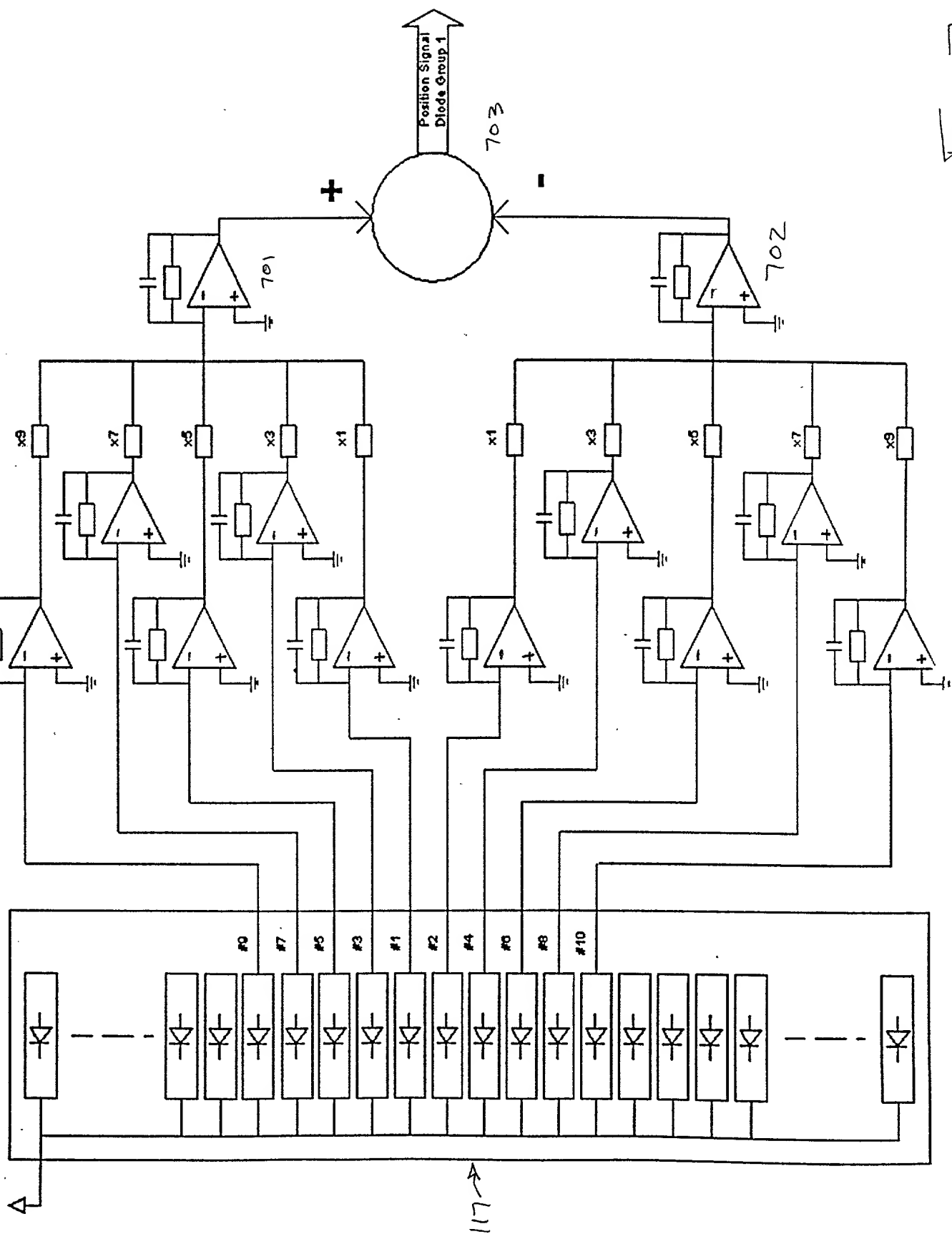


Fig. 7

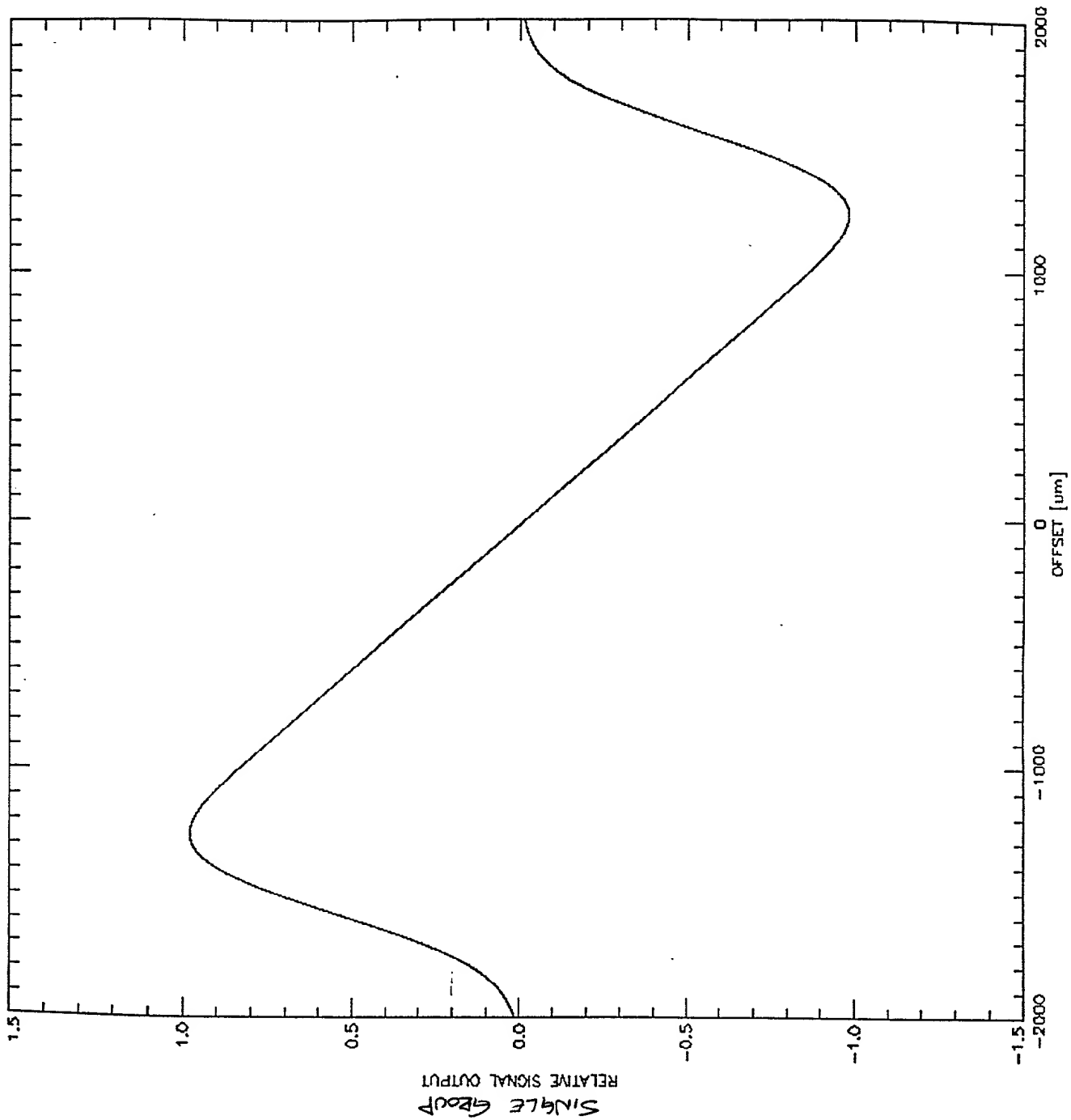


Fig. 8

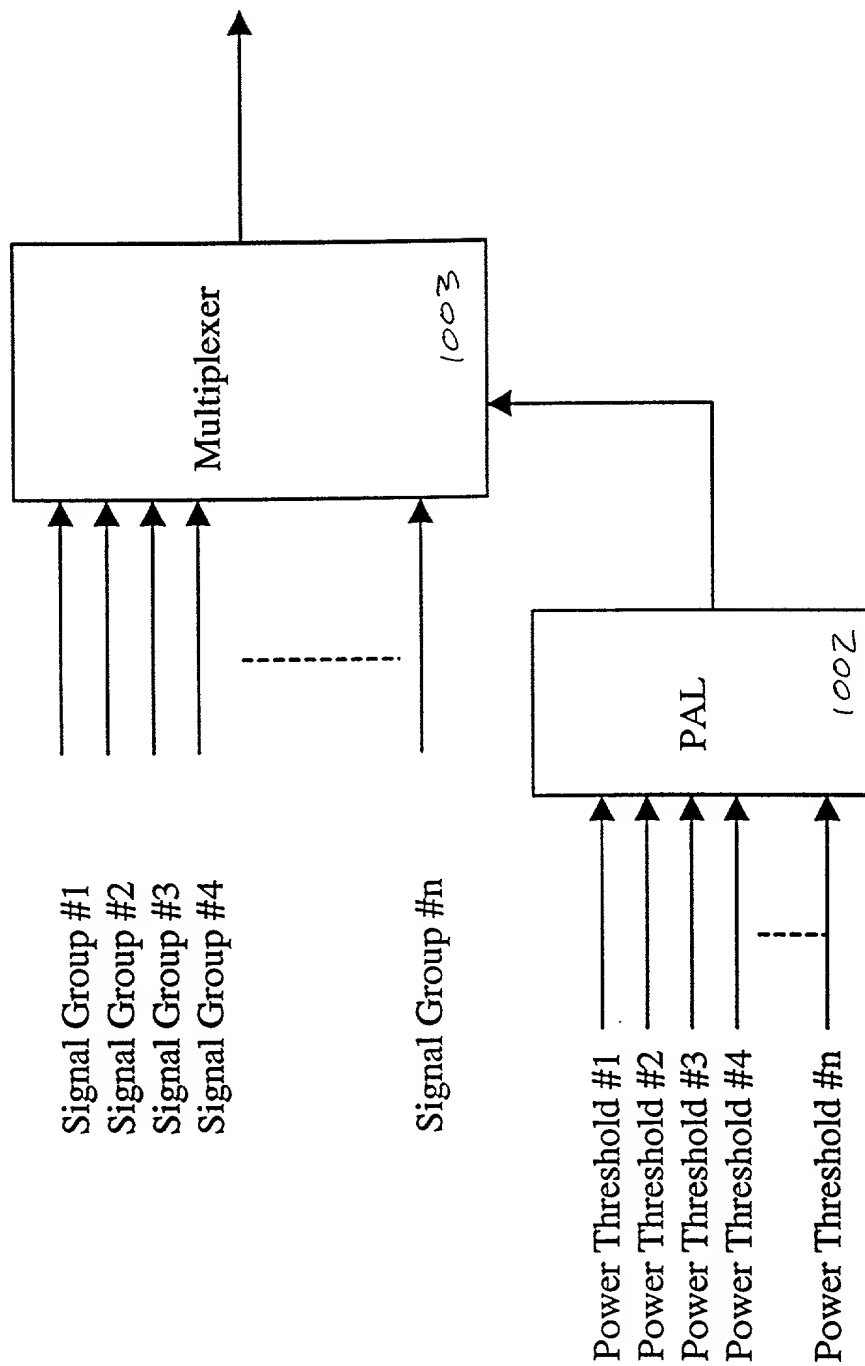


Fig. 10

**DECLARATION
and POWER OF ATTORNEY**

☒ ORIGINAL
☐ CONTINUATION
☐ DIVISIONAL

As a below named inventor, I declare that the information given herein is true, that I believe that I am the original, first and sole inventor if only one name is listed at 1 below, or a joint inventor if plural inventors are named below at 1-4, of the invention entitled:

DETECTION SYSTEM FOR NANOMETER SCALE TOPOGRAPHIC MEASUREMENTS OF REFLECTIVE SURFACES

Which is described and claimed in:

- ☒ the attached specification or
☐ the specification in application Serial No. _____ filed _____
☐ as amended on _____

and for which a patent is sought, and that my residence, post office address and citizenship are as stated below next to my name.

I acknowledge my duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations §1.56(a).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

COUNTRY	APPLICATION NUMBER	DATE OF FILING Month Day Year	PRIORITY CLAIMED UNDER 35 U.S.C. 119
			YES _ NO _ YES _ NO _

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

(Application Serial No.)

(Filing Date)

(Status)

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or Agent(s) to prosecute this application and transact all business in the Patent and Trademark office connected therewith.

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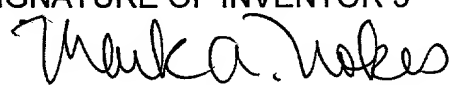
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I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that

such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

SIGNATURE OF INVENTOR 1 	SIGNATURE OF INVENTOR 2 
DATE 11-17-1998	DATE 11-17-98
SIGNATURE OF INVENTOR 3 	
DATE 11-17-1998	

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